Windstorms

Key Points

- The Puget Sound region experiences strong windstorms, including ones with hurricane force winds known as mid-latitude cyclones. These storms are wider that tropical storms. The largest of these was the 1962 Columbus Day Storm. The moderating effects of the Pacific Ocean prevent hurricanes.

- Pineapple Express storms also pack strong winds, but these storms are known more for their rain than wind. They occur when the Jet Stream dips into the tropical regions and up into our area. Wind is just one component of an event that includes flooding, landslides and power outages.

- Tornadoes are very rare in the Puget Sound region but have occurred. Washington ranks 43rd in tornado frequency. Between 1950 and 2005 there were 94 tornados in Washington, compared to 3,204 in Kansas. Most were weak. Those in the Puget Lowland were mostly associated with the Puget Sound Convergence Zone[i].

- Puget Sound is sheltered compared to the Washington Coast, but it can still received sustained winds of 60-70 mph and gusts up to 90mph[ii]. Local terrain has a strong effect on wind speeds. Winds speed up as they move over hills and ridges.

- Power outages are the most significant problem causes by windstorms. The 2006 storm overwhelmed City Light when 49% of customers lost power. While 95% of customers were restored within two days, full restoration took a week.

- Because many windstorms happen in winter and many residents are dependent on electricity for heat, cold-related health problems are a hazard. Several people were killed in King County while heating their homes with charcoal fires during the power outages following the 2006 storm.

- Structural damage can occur at wind speeds as low as 32 mph and destroy wood frame structures at speeds around 100 mph. Seattle's building code requires new structures to withstand 85 mph for three seconds, with modifications to be made for location, but Seattle also has many older buildings. Almost 90,000 homes in Seattle were built before 1939.

- Much of the damage in windstorms comes from falling trees. Areas with heavy tree cover and limited street connections to the rest of the city are vulnerable to power outages and transportation problems.

- Large windstorms are regional events. The more heavily forested areas in the suburban areas are often hit even harder than Seattle is. The result is that resources to aid in recovery can be hard to find.

- Floating bridges are vulnerable to wind and wind-driven waves. The Hood Canal Bridge sunk in 1979 and the I-90 Bridge sunk in 1990. The SR520 Bridge is closed when wind speed reaches 50 mph for 15 minutes. This most recently occurred during the 12/14/2006 storm.

- Scientists project that large windstorms will become less frequent but more intense.

Context

The Pacific Northwest can sometimes receive violent windstorms that reach hurricane strength, but it is not subject to hurricanes like the East Coast. These regional storms are known as mid-latitude cyclones. The mid-latitudes, from 30˚ to 60˚ north, experience a large difference in temperature between the tropics to the south and the arctic to the north. These temperature differences provide the energy source for the storms. The mixing of cold and warm air can create an area of low pressure as a cold front overtakes a warm front.

Mid-latitude cyclones are larger than tropical cyclones and maintain their strength over land more effectively. Areas of low pressure lie at the center of the storms. Theses lows can exceed those of weak to moderate hurricanes.
Tropical cyclones can become mid-latitude cyclones when they push into the mid-latitudes (30˚ - 40˚) through a process called *extra-tropical transition* (ET). The Western Pacific has the greatest number of these events in the world. Current metrological models often fail to anticipate these events. The largest recorded storm to strike the Pacific Northwest, the 1962 Columbus Day Storm was a mid-latitude cyclone.

Wind strength is measured in terms of sustained winds and gusts. Sustained winds are the speeds averaged over one minute near the surface of the earth. Gusts are the three to five second peaks that are often more than 25 – 50% stronger than the sustained winds. Gusts are often what cause the greatest damage.

The El Niño / La Niña cycle is known formally as the El Niño Southern Oscillation or ENSO. It has an effect on the development of major windstorms. The cycle is typically three to seven years. Most major storms occur in the “neutral” years between the two extremes. Because these transitions can be predicted three to six months ahead of time, meteorologists can give communities a general warning that the threat of windstorms is elevated.

These powerful storms are different from this area’s typical winter storms, although both approach Washington from the southwest. Typical “Pineapple Express” storms here have much weaker although still considerable winds and often much more water. They occur when the Jet Stream funnels clouds up from the moist tropics to Pacific Northwest. Typically, these common storms cause much more flooding and landslides than mid-latitude cyclones.

Western Washington experiences several other kinds of wind that are more localized. They typically do not threaten Seattle but can be damaging to communities near Seattle. They are mentioned here to distinguish them from mid-latitude cyclones.

Juan de Fuca Strait Wind Surges

The Strait of Juan de Fuca can act as a wind funnel in the right conditions. In winter a strong surge can push sustained wind speeds to 50 – 70 miles per hour and gusts to 70 – 80 miles per hour. These events usually occur in north Puget Sound with damage occurring as far south as Mukilteo. Two significant events of this type occurred on December 17, 1990 and October 28, 2003.

Cascade Downslope Winds

These storms are caused by a build-up of high pressure east of the Cascades. When a low pressure system moves into the Puget Lowlands, the dammed up air east of the mountains comes surging through the lower passes. Stampede Pass is the lowest pass in the region and the area immediately below it, Enumclaw, routines sees strong winds as a result. Occasionally, these winds push all the way to Puget Sound south of Seattle. During one of these events, Fife and Federal Way can be experiencing winds of 50 -60 miles per hour while in Seattle the wind speed is close to zero.

Tornadoes

Tornadoes are unusual events in the Pacific Northwest. There have been several recorded in the Puget Lowlands. Tornadoes are ranked on the Fujita Scale from 0 to 5. They are an estimate of wind speed based on the damage pattern. The largest tornado to occur in the Puget Sound area was an F3.

History

The Pacific Northwest is periodically hit by mid-latitude cyclones and other more localized wind events. The coast usually records more violent winds, but the Puget Sound has also has its share of powerful storms.

Most storms happen in late fall and winter. Of the nine major storms to hit Seattle since 1962, seven have occurred in winter. The other two occurred in early fall and early spring. Nearly half happened in November, while two struck in February.

1943: Official records at the Federal Building show one occurrence of 65-69 mph winds[iii]. A weather station at the Federal Building in downtown Seattle showed that between 1935 and 1959, wind speed exceeded 50 miles per hour 37 times and 60 mph six times[iv].

9/28/1962: An F1 tornado damaged eight homes in the Sand Point/View Ridge area before travelling across Lake Washington and damaging homes in the Juanita area of Kirkland.

10/12/1962: “Columbus Day Storm”. It had 85 miles per hour sustained winds equal to hurricane speed. Higher wind speeds of 150 mph on the coast demonstrated the protection that the Olympic Mountains give the region. Nevertheless, the damage was widespread. Throughout the region, 46 people died, 53,000 houses were damaged and the power went out in many areas of Washington. It is not clear how much of this damage was in Seattle. Main trunks carrying power to Portland were destroyed.

12/12/1969: Tornado strikes the Kent valley. The storm causes 1 injury and no deaths. It damaged a billboard and a farm.

3/26/1971: Sixty mph winds forced the closure of the Evergreen Point Bridge. The wind also ripped panels off the Seafirst building, forcing the Downtown Library to close. Two people died.

2/13/1979: The Hood Canal Bridge breaks apart in a violent storm.

2/19/1981: Wind and lightning damaged at least one home and left 100,000 without power in Seattle and King County. This storm began as a tropical cyclone.

11/14/1981: This storm caused power outages, closed the bridges, and damaged buildings.

11/24/1983: "Thanksgiving Day Storm." This storm surprised even the National Weather Service, revealing that long warning periods cannot always be counted upon. Downed trees were a leading cause of outages that left 75,000 without power in King County. The wind also damaged roofs and broke boats loose from their moorings.

11/25/1990: The Old Mercer Island Bridge sank in a storm. The sinking was caused in part by construction waste in the floats under the bridge. (See Infrastructure Failure).

11/16/1991: 400,000 were left without power in the Seattle area after the worst storm since the Thanksgiving Day Storm of 1983.

1/20/1993: "The Inaugural Day Storm." Massive outages occurred in Seattle, although the power was out the longest in the suburbs. Debris littered the road and traffic came to a stop as traffic lights failed. Winds in the Puget Sound gusted to 60-70 miles per hour.

12/14/2006: Unusually intense levels of rainfall in a very short period of time were immediately followed by very heavy winds up to 69 miles per hour that felled power poles and large, mature, healthy trees. Three-fourths of an inch of rain fell in less than 45 minutes in some areas of the city. As a result, more than 1.5 million customers were without power throughout western Washington and Oregon, some for longer than a week. Making the situation worse, a late-afternoon Seahawk game in Seattle meant many more motorists attending the game were further delayed from getting home because of the tempest.

Likelihood of Future Occurrence

While there has been a projection that violent storms will increase in frequency and intensity globally, trends for mid-latitude cyclones in the Eastern Pacific have shown a *decrease* in frequency but an *increase* in intensity. (Dello, 2010)

Vulnerability

Trees and wet soils make windstorms worse in the Pacific Northwest. The northwest's tall conifers are often shallow rooted and prone to being uprooted, especially when the ground is saturated with water. Unfortunately, the ground is often saturated in the late fall and winter when the majority of these powerful storms arrive. Seattle has fewer trees than suburban and rural areas, but it still has substantial numbers of them.

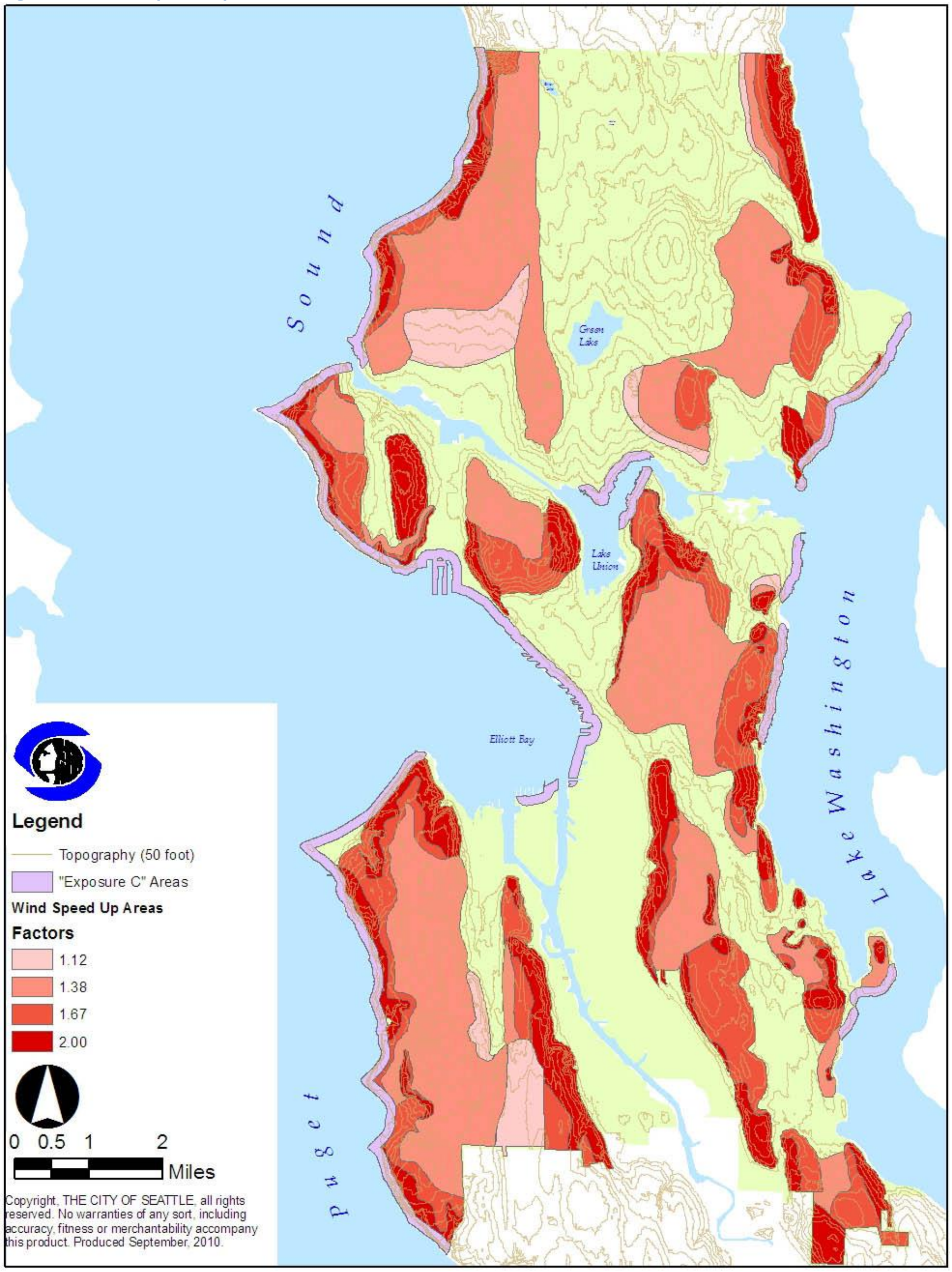
Falling trees and branches are the major hazard in windstorms. They snag power, cable television and telephone lines and bring them down, causing outages. When they fall across roads, they interrupt transportation. A downed tree can usually be cleared quickly; when accompanied by downed power lines, the job takes much longer. Finally, trees pose a direct hazard to homes.

Wind can cause direct damage to buildings. Seattle's Building Codes, which are built on the International Building Code, specify that structures must withstand a load caused by a three second gust of 85 miles per hour. Structural engineers apply this speed to structures using a formula to calculate wind load. Seattle's coast and hills affect this load. Winds are stronger over water and along hillsides. Areas on

Figure 1 that are shown in purple and red are prone to stronger winds. During a windstorm on December 12, 1995, a ship just outside of Elliott Bay reported a gust of 90 miles per hour.
Areas with limited access, such as Magnolia, can become isolated if trees fall on the few roads that lead into them. This information suggests that North and West Seattle have a higher vulnerability than the rest of the city since they are the most heavily forested.

Wind driven waves are another hazard for the city. Large waves can endanger the floating bridges. On average, more than 260,000 vehicles move over these bridges daily[v]. This traffic gives them enormous socioeconomic importance. Their susceptibility to damage and their value to the local economy make them vulnerabilities for Seattle.

Figure 1. Wind Speed Up Areas[vi]



During the 1993 Inaugural Day Storm, trees falling on buildings, power and telephone lines and on roads caused most of the damage. In addition, falling trees and limbs damaged hundreds of homes, and fires started by fallen power lines damaged several buildings. Some major public structures suffered more than superficial damage, e.g., both of the floating bridges across Lake Washington, I-90 and SR 520, had damage to pontoons that keep the bridges afloat[vii]. Extensive damage occurred from uprooted trees and brittle trees that broke or whose branches broke off and fell onto power lines, buildings and roadways.

If windstorms are accompanied by heavy rain or followed by extreme cold, the effects of the windstorm are multiplied. As detailed in other chapters, the rain can lead to urban flooding and landslides while extreme cold will increase the hardship caused by power outages.

Consequences

Windstorms are a regular part of Pacific Northwest weather as are rain driven flooding and snow. There is research to suggest that mid-latitude cyclones, the cause of our most damaging storms, may be increasing in intensity[viii].

Windstorms cause direct physical damage to structures, infrastructure for power and telecommunications and coast bluffs. They cause indirect damage to the economy through power outages and inhibiting the transportation system. Many people cannot or choose not to come to work because they fear long drives or must take care of damage at home. For local governments, debris removal can place a strain on budgets. Despite these costs, the biggest economic problem from windstorms is property damage. Families can incur major expense even from light damage to roofing or siding. The 2006 record intensity storm of torrential rains and high-velocity winds took a toll on Seattle's residents and their property. Scores of city residents experienced thousands of dollars in damage to their homes and businesses from downed trees falling onto house roofs and cars, flooding inside homes and businesses, and severe roof and siding damage.

Even moderate wind speed can damage buildings. Wind speeds as low as 32 miles per hour can drive objects through walls[ix]. Other research shows that wood-frame and unreinforced masonry structures can be damaged or even destroyed at speeds less than 100 miles per hour and that a home constructed according to any of the major codes in the U.S. will lose its roof in winds from 80 to 120 miles per hour[x]. In Seattle, winds have exceeded this threshold demonstrating that widespread structural failures are possible.
Besides doing extensive property damage directly, wind can devastate vegetation and utility lifelines. The 2006 storm caused great damage to city property and infrastructure, with preliminary damage estimates at $16 million.

Besides being an inconvenience to property owners and municipal governments who must clean up debris, falling trees are also a safety risk. In the 2006 windstorm, sections of dozens of major arterials and hundreds of neighborhood streets were blocked, mostly by fallen trees. An estimated 700 trees fell on public property.
Power outages are another widespread problem. Parts of the Eastside lost electricity for days after the 1993 Inaugural Day Storm. These outages also affect traffic lights, making driving a long and difficult process. Finally, downed power lines and transformer explosions are health risks.

The bridges pose another safety risk. If a windstorm develops suddenly, as in 1983, it could hit them before the State Department of Transportation could close them preemptively.

Seattle has experienced severe windstorms regularly. The most likely situation is that this pattern will not change. Seattle can expect storms up to the magnitude of the Columbus Day storm. While the hazard intensity may not change, Seattle has grown and our economy has become more time dependent. This increase in vulnerability means that damage is more likely to be higher damage from windstorms. While windstorms are always dangerous, their main effect has been economic.

If it is true that mid-latitude cyclones are increasing in intensity and number, Seattle could face a storm even stronger than the Columbus Day Storm. When combined with Seattle's density and aging infrastructure, especially SR 520 and seawall, the consequences of such an intense storm could be large. If Seattle experienced a "super storm," it could cause major building damage, widespread power outages, infrastructure damage, landslides, coastal flooding and transportation gridlock. With increased structural damage, it is likely that the number of injuries and fatalities would also increase.

Most Likely Scenario

Seattle faces another storm similar to the 1993 or 2006 storms: numerous downed trees, scattered outages, limited structural damage. City Lights aggressive tree trimming mitigates power outages and its power outage management system speeds restoration.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	The Seattle had experienced major windstorms nearly every decade. The impact of climate change is not clear, but some evidence suggests that it could increase the frequency and intensity of mid-latitude cyclones which are the Pacific Northwest's source of major wind storms.
Geographic Scope	5	Mid-latitude cyclones are wide storms. The one in this scenario affects the entire Central Puget Sound region.
Duration	1	The storm itself lasts for eight hours. Short term response and recovery lasts for another three days.
Health Effects, Deaths and Injuries	2	Nobody is killed in the storm, but 8 people are injured by debris.
Displaced Households and Suffering	2	Building damage, power outages and urban flooding drive 60 people from their homes. 25% of the city loses power. City Light's outage management system enables the utility to more quickly respond than it could during previous storms.
Economy	2	Many businesses close during the storm. Retail businesses are hit the hardest.
Environment	2	The storm produces major amounts of debris. Most is natural but non-compostable debris must be transferred to landfills.
Structures	2	Many buildings have minor roof damage, but 9 have major structural damage (roof failure) and are red tagged. 25% of the city loses power. City Light tree trimming operations prevent more widespread outages.
Transportation	2	Debris, fallen trees, traffic light outages and downed power lines cause major traffic and transit backups. The airports and marine ports are able to resume operations quickly after the storm.
Critical Services and Utilities	2	Power and fire crews must work together to coordinate service restoration in a way that does not tie up fire units. 25% of the city loses power.

Confidence in Government	1	The public feels that the government responds quickly to the storms. Recovery happens quickly and the public's confidence in government is boosted.
Cascading Effects	1	Aside from the power outages which are the major impact of the storm, it does not cause any secondary effects.

Maximum Credible Scenario

Climate change fuels a mid-latitude cyclone even stronger than the 1962 Columbus Day storm. Winds are recorded at 90 mph at West Point. The ground is saturated from previous heavy rain. Many trees down and power lines down. The whole region is affected. Waves damage a floating bridge heavily. The storm hits during a king tide causing heavy coastal flooding. Several piers on waterfront affected.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	This storm is record setting. One this powerful has never occurred but there is evidence to suggest that mid-latitude cyclones will increase in intensity.
Geographic Scope	5	This storm is massive. It affects the entire Pacific Northwest coast from Oregon to British Columbia. Coastal areas receive the strongest winds of 120 mph. The storm maintains strength far inland and affects areas east of the Cascades as well.
Duration	2	The storm itself lasts for 10 hours. It takes public safety and infrastructure crews 36 hours to stabilize the incident. Short term recovery takes another 10 days when most services are restored, but heavily damaged areas require months to years to fully recover.
Health Effects, Deaths and Injuries	2	Regionally, the storm kills 65 people. In Seattle itself, there are 9 fatalities.
Displaced Households and Suffering	3	Building damage, power outages and urban flooding drive 95 people from their homes.50% of the city loses power. City Light's outage management system enables the utility to more quickly respond than it could during previous storms.
Economy	3	Many businesses close during the storm. Retail businesses are hit the hardest. Power is out for an extended period and more business have serious physical damage. Many lack adequate business continuity plans. 25% of the businesses without plans that are damaged fail.
Environment	3	The storm produces massive amounts of debris. Most is natural but non-compostable debris must be transferred to landfills. Secondary hazards (landslides, transportation accidents) have caused hazardous material spills. Heavy rain preceding the wind has caused urban flooding. Flood waters contain sewage from broken waste water lines.
Structures	3	Thousands of buildings have roof damage. Most damage is minor but 128 buildings have to be yellow tagged and 32 are red tagged. 50% of the city is without power. Urban flooding impacts another 45 structures. Coastal flooding damages two piers downtown.

Category	Impacts 1 = low 5 = high	Narrative
Transportation	4	Debris, fallen trees, traffic light outages and downed power lines cause major traffic and transit backups. Due to the overwhelming amount of debris, surface transportation is disrupted for a week. Landslides have damaged several major roads and bridges. The airports and marine ports are able to resume operations quickly after the storm.
Critical Services and Utilities	4	Power outages are major problem throughout the city. 50% of the city loses power. Public safety responders have a difficult time reaching many parts of the city. City Light and Fire must work to coordinate guarding downed power lines, service restoration and fire/ems response.
Confidence in Government	3	As the power outages and transportation disruption lingers, the public becomes impatient. Many cannot understand why short-term recovery is taking so long.
Cascading Effects	4	The storm causes many secondary effects: landslides, urban flooding, coastal flooding and hazardous materials incidents.

Conclusions

The Pacific Northwest is prone to violent windstorms. Although it is difficult to predict trends, the data suggest an increase in intensity of windstorms. As Seattle grows, so will the damage caused by them.

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[i] Mass, 2009.
[ii] Mass, 2009.
[iii] US Weather Bureau, 1959.
[iv] US Weather Bureau, 1959.
[v] Seattle Department of Transportation, 2003
[vi] The map shown is a resource for engineers designing structures for wind loads in Seattle. It shows wind exposure and terrain adjustment factors, was derived from the wind load provisions in ASCE 7-02, and is appropriate for those using ASCE 7 or SEAW's Rapid Solutions Manual in their designs.

The color-coded areas identify wind speed-up areas in Seattle, with acceptable Kzt values and areas defined as being Exposure Category C. The Kzt values will be accepted by DPD as default values for Kzt in lieu of the calculated values required by Section 6.5.7.2 of ASCE 7-02. Similarly the areas identified as Exposure Category C will be accepted by DPD in lieu of a determination required by Section 6.5.6.3 of ASCE 7-02. NOTE: There are no areas in Seattle that DPD requires to be considered as Exposure Category D.
[vii] (Dello)
[viii] Graham and Diaz, 2001.
[ix] Marshall, 1993.
[x] Liu, 1993.